INTERPRETATION OF SIDE-SCAN SONAR RECORDS OF A PORTION OF THE INNER NORTH CAROLINA CONTINENTAL SHELF BETWEEN OREGON INLET AND KITTY HAWK

by

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EXECUTIVE SUMMARY

Side-scan sonar records, vibracores, bathymetry, and seismic reflection profiles were used to characterize seafloor types over 138 square nautical miles (470 km^2) of the North Carolina inner continental shelf (Oregon Inlet to Kitty Hawk). Five seafloor categories were defined by acoustic characteristics observed on side-scan sonar records (and correlated to sediment types using textural analyses of vibracores). These are: 1) a uniform, light gray sonar record (fine sand); 2) a medium- to dark-gray sonar record (medium to coarse sand); 3) mixed acoustic returns producing a "patchwork" of light gray and medium- to dark-gray areas (fine sand overlying medium to coarse sand); 4) a relatively weak acoustic return with small areas of stronger (darker) reflections producing a "pock-marked" appearance (mud with sand lenses); 5) low-relief scarps evident on the side-scan sonar records (eroded compact, cohesive mud).

These seafloor categories (and associated sediment types) can be predicted with relatively high confidence from bathymetry and shallow stratigraphy derived from single-channel seismic reflection profiles. Seafloor category 1 (fine sand) occurs on bathymetric highs in the southern part of the study area, whereas category 2 (medium-coarse sand) occurs in bathymetric lows in the southern part of the study area. Seafloor category 3 (mixed fine and medium-coarse sand) occurs on slopes joining bathymetric highs and lows. Seafloor categories 4 and 5 (mixed mud/sand and compact mud) are found on the relatively deep, flat-lying seafloor in the northern portion of the study area.

Few vertical or near vertical scarps (seafloor category 5) characteristic of hardbottoms in other regions of the North Carolina continental shelf (e.g. Onslow Bay) were identified. The areal extent of these hard-bottom sites is small; with no feature occupying more than 0.5 km^2. Seafloor category 4, however, is also interpreted to be hardbottom, and it covers a significant portion of the northernmost part of the study area. The distinctive "pock-marked" acoustic signature of this hardbottom makes it identifiable even on poor quality sonograms.

Assuming seafloor conditions along the available side-scan and seismic profiles are representative of conditions throughout the area studied, hardbottoms appear to be most prevalent across the northern (relatively low-relief, deep) portion of the study area whereas the greatest sand resource potential is found across the central and southern (relatively high-relief, shallow) portions of the studied area. These conclusions provide an important step toward understanding relationships among seafloor geomorphology, stratigraphy, and the distribution of sand resources across this portion of the North Carolina inner continental shelf and demonstrate the utility of integrated geophysical, sedimentological, and stratigraphic data sets for sand resource evaluation.

INTRODUCTION

As part of the continuing study of sand resources off the northern Outer Banks of North Carolina under a cooperative federal/state program, the United States Minerals Management Service authorized a reconnaissance survey to ascertain the potential for sand resources across a portion of the North Carolina continental shelf in 1994. The proposed survey area extended seaward from the shoreface for 15 nautical miles (nm) or 28 km and along shore from Oregon Inlet to Duck (26 nm or 48 km; Fig. 1). Thus, the original survey area encompassed 390 nm^2 (1,338 km^2) of the inner continental shelf.

During the summer of 1994, investigators from North Carolina State University (NCSU) and the North Carolina Geological Survey (NCGS) obtained side-scan sonar and normal-incidence, single-channel (high-resolution) seismic reflection profiles (Fig. 1) aboard R/V *Seaward Explorer* through the area on an approximately 2-nm grid. In 1996, the NCGS obtained 58 vibracores from specific targets within the study area (Fig. 1). These cores have recently been processed, described, and analyzed; and the cores are archived at the Coastal Plain Office of the NCGS in Raleigh. These data still must be worked up for publication.

Normal-incidence seismic reflection profiles were initially processed and interpreted by Boss and Hoffman (1997) to provide an overview of the geology and identify areas interpreted to have the highest sand resource potential. Later, Stephen W. Snyder of NCSU processed the seismic data, interpreted the profiles, and produced digitized line drawings of the seismic reflection data under contract to the NCGS (NCGS, unpublished data). Based on interpreted seismic records and integration of textural and descriptive data from the vibracores, the sand resource potential of the study area was evaluated in more detail and a revised potential sand resources map was produced (Hoffman, 1998).

Presently, an environmental assessment of the revised sand resource area is underway. An issue of particular importance with respect to the environmental study of this area is the location, distribution and areal extent of "hard-bottom" areas (Riggs et al., 1998; Riggs et al., 1996) that might be adversely affected by future sand dredging operations. Riggs et al. (1998) define a generic term for "hard-bottom" as "…seafloor with a semi-indurated to indurated surface". In North Carolina, this terminology is used to refer to seafloor whose physical properties range from unlithified but compact and cohesive mud to well-cemented limestone and calcarenite (Riggs et al., 1996). Semi-indurated to indurated seafloor areas are habitats that typically support rich and diverse communities of sessile benthos. If seafloor is sufficiently indurated and immobile to support such growth, the descriptive term "live-bottom" is commonly applied regardless of the degree of lithification or cementation of bottom sediment. Since live-bottom areas are important oases of biological productivity (Cahoon and Cooke, 1992) with great value to North Carolina commercial fisheries (Grimes et al., 1982; Gutherz, 1982; Manooch et al., 1981), identification and mapping of live-bottom sites and assessment of the possible impacts of sand dredging on these sites is crucial.

The objectives of this study were 1) to review and interpret available side-scan sonar records along survey tracklines within the revised sand resource area in order to identify various seafloor types, 2) characterize these seafloor types by comparing their observed acoustic signature to available cores, bathymetric data, and normal-incidence seismic reflection profiles, 3) generate maps of seafloor types along tracklines in a GIS-compatible format, and 4) determine the areal extent of possible hard-bottom or live-bottom localities. This report presents the results of this work.

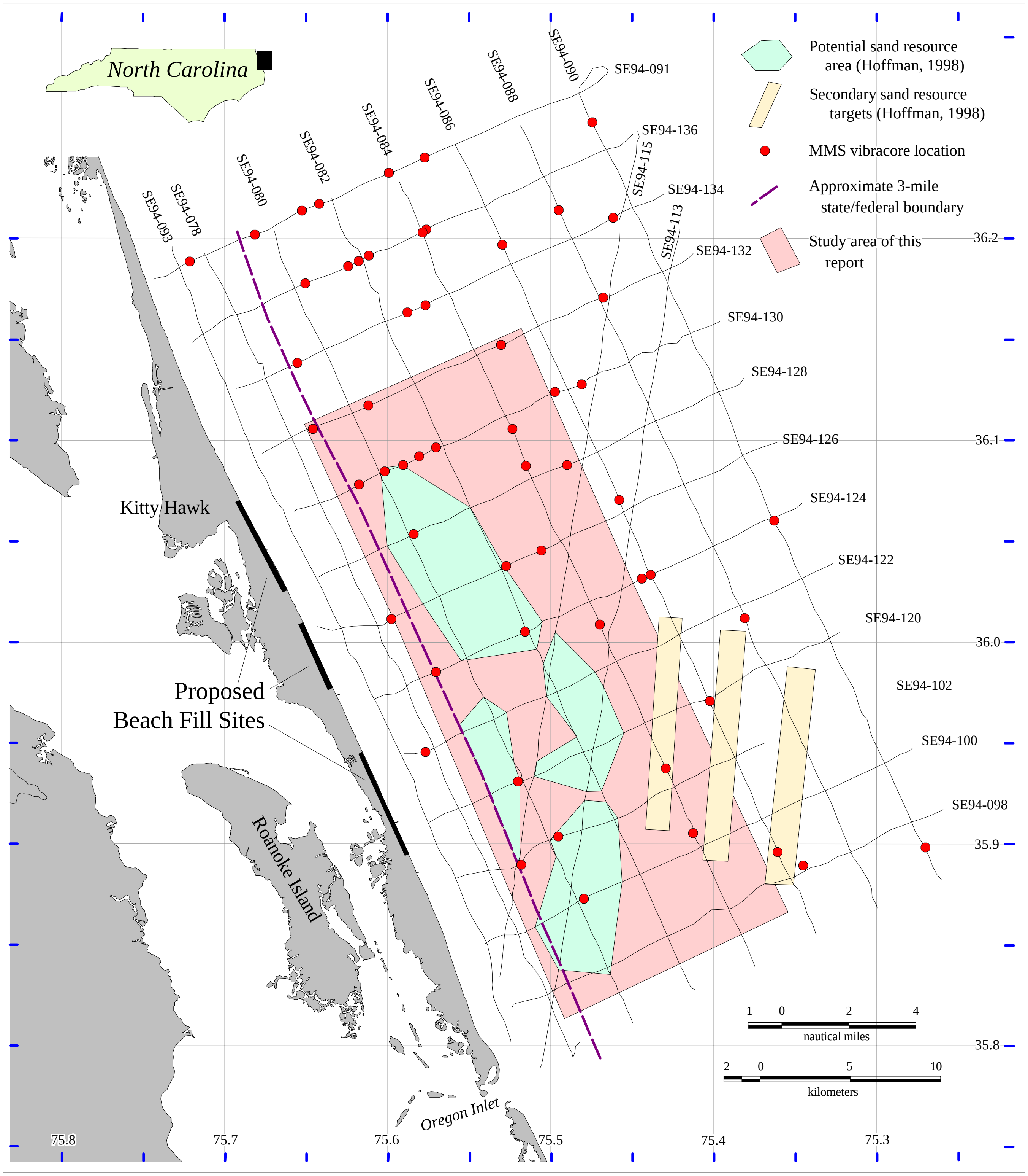


Figure 1. Map showing MMS/NC Sand Resources Task Force study area with seismic and side scan sonar tracklines, vibracore sites, potential sand resource areas, and study area of this report.

DATA BASE

All side-scan sonar records were obtained aboard R/V *Seaward Explorer* during the 1994 survey. Original analog sonograms were available for review and interpretation, but data relating to specific operating parameters of the side-scan sonar instrument during acquisition were not available. Thus, it was not possible to determine whether slight changes in acoustic character were related to actual variability of seafloor physical properties or adjustment of operating parameters (such as gain) at the time of acquisition. As such, it was necessary to establish qualitative criteria for categorizing seafloor types.

The revised sand resource area (Hoffman, 1998) includes approximately 120 nm (222 km) of side-scan sonar data from the original data base oriented on a 2-nautical mile orthogonal grid with survey tracklines running parallel and perpendicular to shore (Fig. 1). All tracklines within this area were located in federal waters, beginning approximately 3 nm (5.5 km) offshore and extending seaward to 8 nm (15 km). Thus, the data analyzed for this report occupied 138 nm^2 (470 km^2) within the original 390 nm^2 (1,338 km^2) survey area.

All sonograms were recorded with a 400-m swath, though in some instances shallow water limited the effective imaging area on the seafloor to less than 400 meters. Time-event marks on the sonograms were cross-referenced to known navigation fixes associated with normal-incidence seismic reflection data and the GIS basemap.

RESULTS

Five principal seafloor types were defined by the acoustic character of the seafloor observed on analog (hard copy) side-scan sonar records: 1) a relatively weak acoustic return producing a generally uniform, light gray sonar record; 2) a moderate to strong acoustic return producing a medium- to dark-gray sonar record; 3) mixed weak and strong acoustic returns producing a sonar record with mixed light gray and medium- to dark-gray areas (termed “patchwork” pattern); 4) a relatively weak acoustic return with small areas of stronger (darker) reflections producing a characteristic “pock-marked” appearance on sonar records; 5) potential “hard-bottom” or “live-bottom” identified by the presence of small scarps evident on the side-scan sonar records. Detailed descriptions of these seafloor types follows. Their distribution along survey tracklines is shown in Plate1.

Light Gray Sonogram (Weak Acoustic Return)

The most commonly observed acoustic signature on side-scan sonograms is a relatively weak acoustic return producing a uniform, light gray image (Fig. 2). Locally, ripple marks are visible on sonograms of this seafloor type. Similar side-scan signatures in Onslow Bay (central North Carolina shelf area) were shown by Riggs et al. (1998) to be a mobile sand sheet.

Comparison of areas of this seafloor type to normal-incidence seismic profiles of the area indicates that it coincides with north-south trending bathymetric highs. The upper part of these highs typically is seismically transparent — suggesting relatively uniform sediment composition. The seismically transparent unit averages 3.3 ms (2-way travel time) or about 2.8 m. thick. The unit is most extensive in the southern part of the sand resource area.

Textural analyses of sediment samples in cores through this seafloor type indicate that it is dominantly fine sand with relatively small quantities of mud and zones of medium to coarse quartz

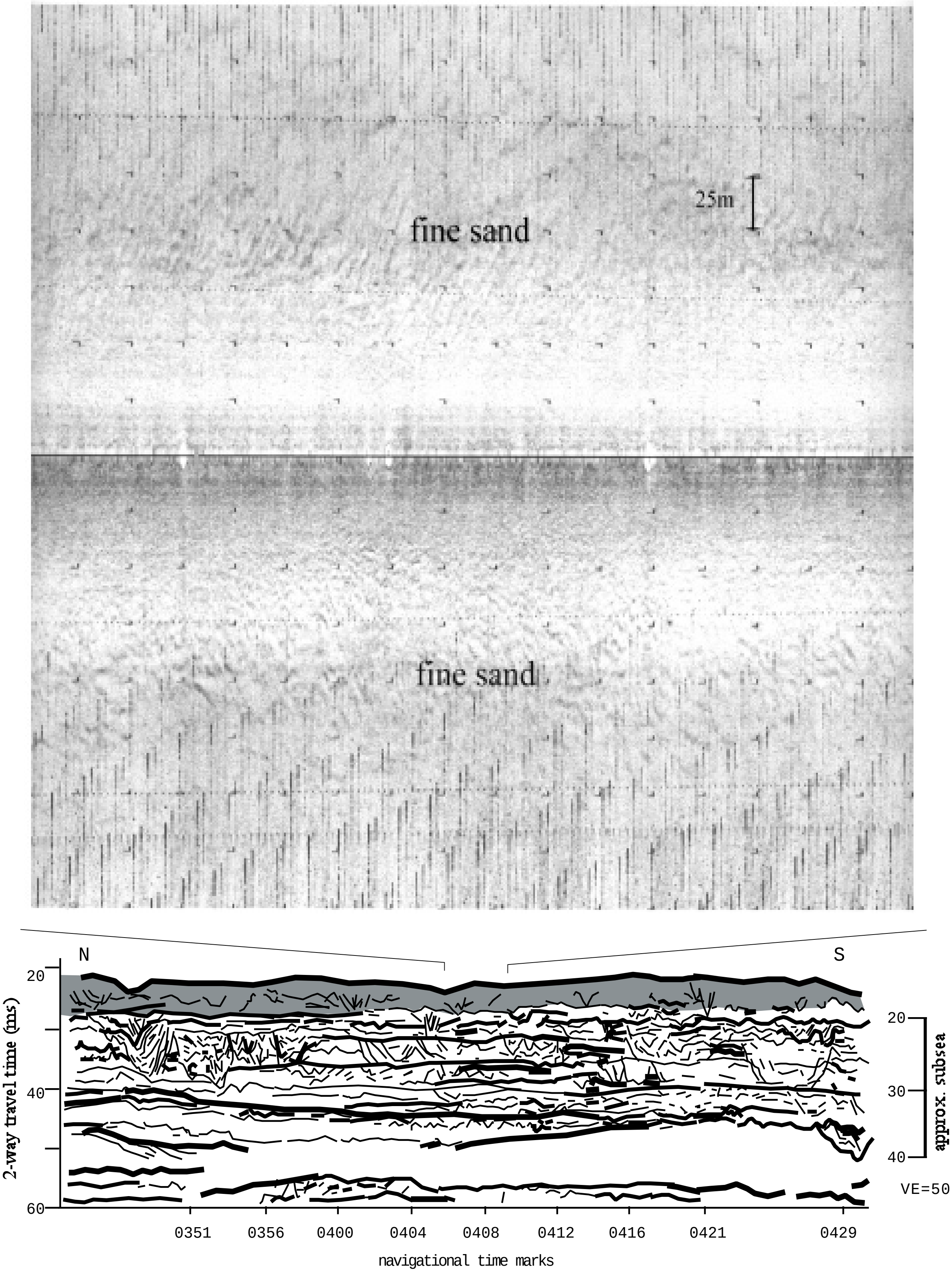


Figure 2. Sonogram showing light gray side scan pattern (fine sand) and correlative seismic section from line SE94-080 between lines SE94-126 and SE94-128. Seismically transparent unit is highlighted.

sand and shell gravel near its base (NCGS, unpublished data).

Medium to Dark Gray Sonogram
(Moderate to Strong Acoustic Return)

Seafloor yielding a moderate to strong acoustic return produces a sonogram with medium to dark gray tone (Figs. 3 and 4) and is the second most common seafloor type within the study area. This signature is typically ripple-marked, with ripple crests spaced from 1 - 1.5 m. Ripple marks are best displayed on sonograms with survey tracks parallel to the ripple crests. On sonograms which traverse perpendicular to the ripple crests, the seafloor record is typically uniform medium to dark gray. Comparison of areas of this seafloor type to normal-incidence seismic records indicate that this seafloor type usually coincides with troughs located between the bathymetric highs of the southern part of the study area.

The stronger acoustic return from this seafloor indicates that the sediment is coarser than that producing uniform light gray sonograms. Unfortunately, no vibracores are located where this acoustic signature is present. However, based on observed depth of this seafloor type in troughs, it is possible to extrapolate laterally on normal-incidence seismic sections to locations where vibracores penetrated sediments on bathymetric highs and apparently sampled sediment of this seafloor type near their base. Several cores penetrate the seismically transparent unit associated with the light gray sonogram signature. Medium to coarse sand (>30%) with gravel sized material (<15%) occurs in the basal part of these cores. If exposed in bathymetric troughs, this sediment would yield the medium- to dark-gray acoustic signature on sonograms.

“Patchwork” Sonogram (Mixed Weak and Strong Acoustic Return)

The third seafloor type observed within the study area is a mixed weak and moderately strong acoustic return generating a characteristic “patchwork” pattern on sonograms (Fig. 5). Comparison of this seafloor type to seismic reflection records indicates that it is normally associated with slopes between bathymetric highs and lows. In fact, it is not unusual to observe the patchwork seafloor type grading upslope to uniform light gray (relatively weak acoustic return) and downslope to medium or dark gray (relatively strong acoustic return) seafloor types.

This geometry suggests that the patchwork seafloor type may result from fine sand transported downslope and partially covering coarser sediment exposed in troughs, or alternating fine and coarser grained lenses of single stratum *in situ*. The vibracores within or proximal to this sonogram pattern do not provide definitive support for one interpretation over the other.

“Pock-marked”Sonogram (Mixed Weak and Strong Acoustic Return)

The fourth seafloor category recognized within the study area is characterized by a relatively weak (light gray) acoustic return with small linear to rounded areas (perhaps several m^2) of stronger reflectivity producing a distinctive “pock-marked” appearance on sonograms (Fig. 6). This seafloor type is restricted to the northernmost portion of the study area, and is predominantly over an area of relatively flat-lying seafloor at a depth typically >20m.

The occurrence of this seafloor type within the northern (deeper) sector of the study area suggests that it represents a stratum cropping out on the seafloor which is different than those observed to the south. Examination of seismic reflection profiles associated with the region where “pock-marked”

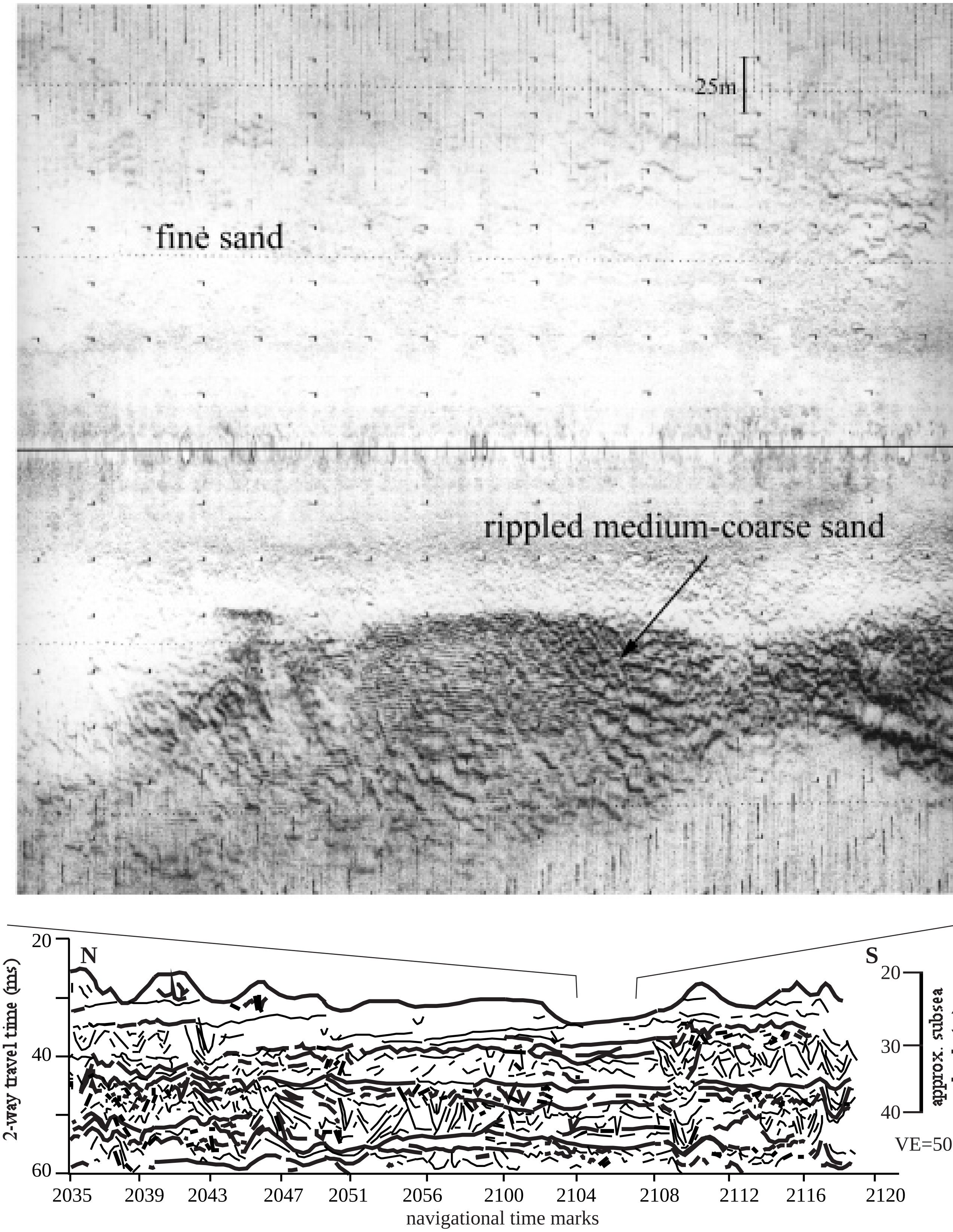


Figure 3. Sonogram showing light gray (fine sand) and rippled medium to dark gray (medium to coarse sand) side scan patterns and correlative seismic section from near south end of line SE94-084. Coaser material occurs just west of side scan center line in bathhymetric low area.

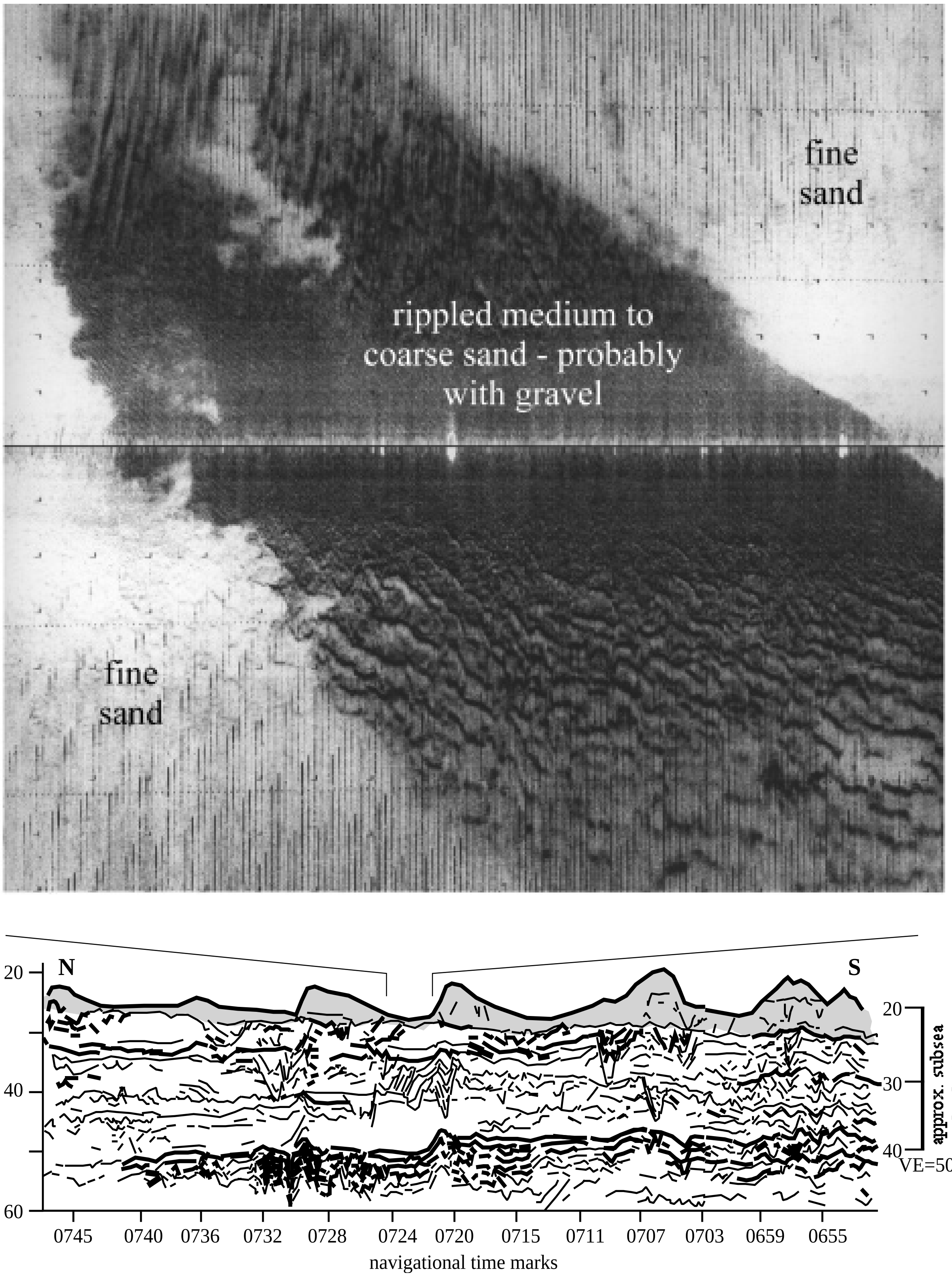


Figure 4. Sonogram showing rippled dark gray side scan pattern (medium to coarse sand and gravel) and correlative seismic section from line SE94-080 just north of line SE94-098. Pattern occurs in a NE-SW trending bathhymetric low. Seimically transparent unit is shaded.

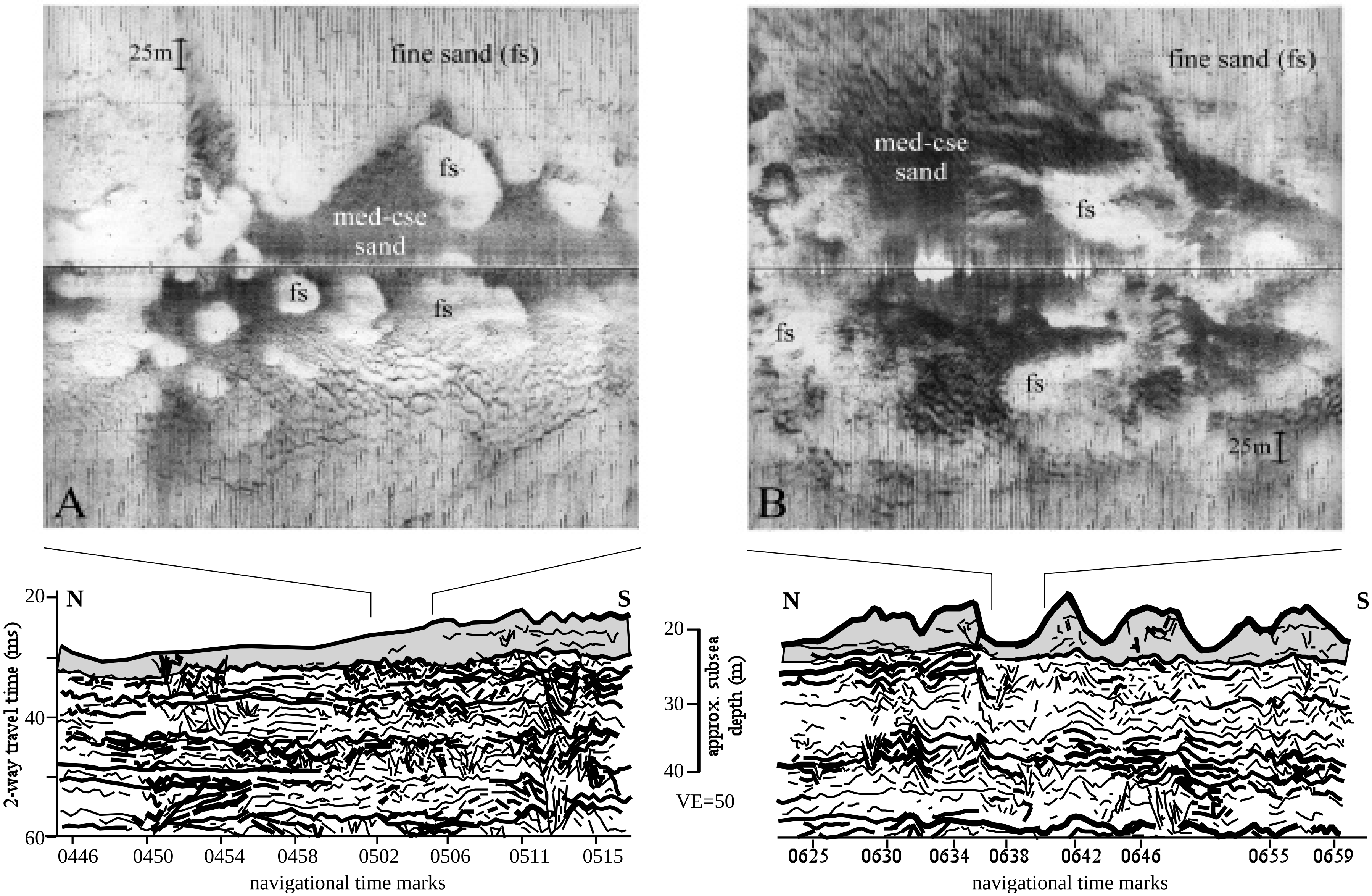


Figure 5. Sonograms showing "patchwork" side-scan pattern and correlative seismic sections from line SE94-080. Pattern occurs on slopes between bathymetric highs and lows and is interpreted as resulting from fine sand from high areas being deposited over coarser sand cropping out in low areas. seismically transparent unit is shaded.

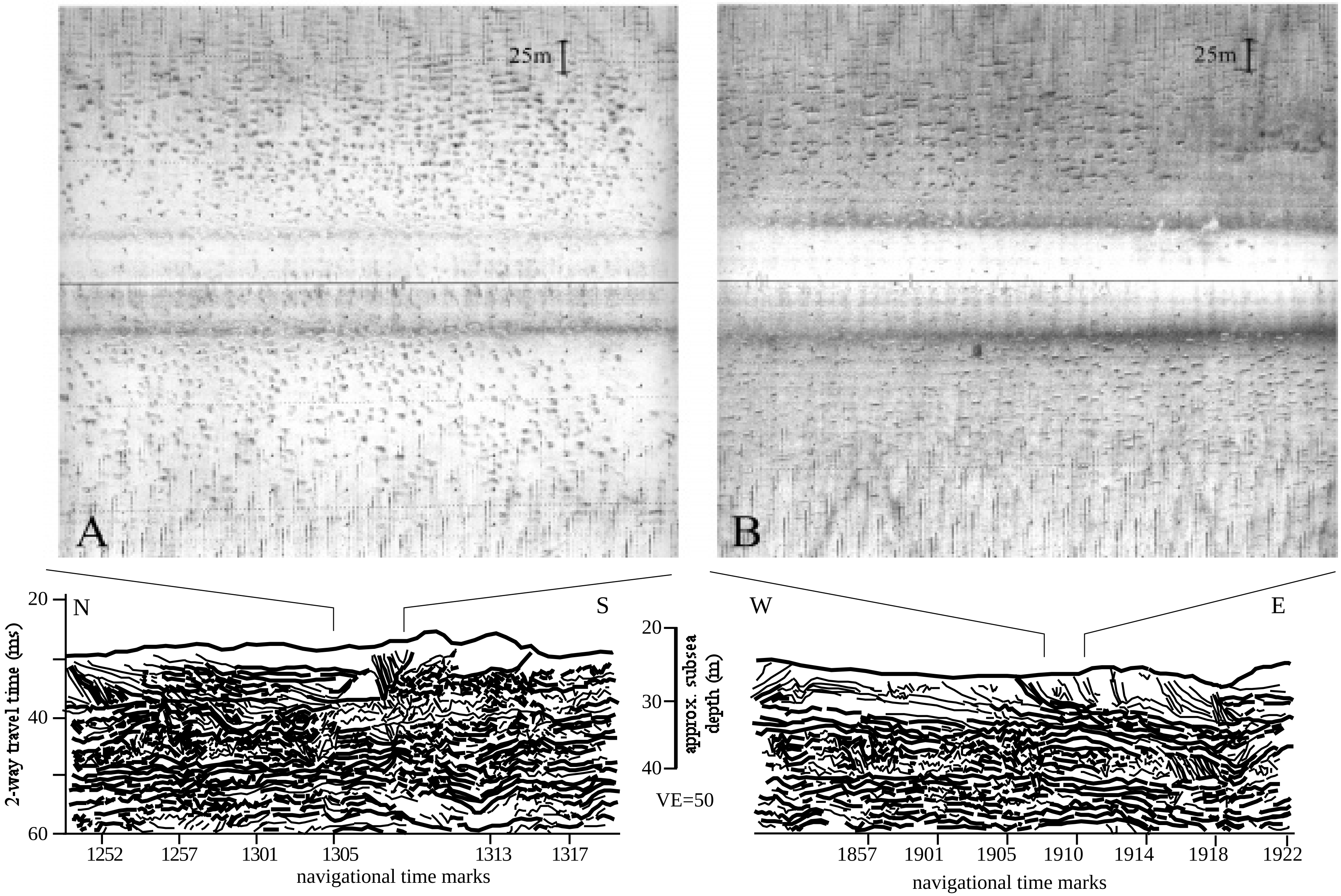


Figure 6. Sonograms showing "pock marked" side-scan pattern and correlative seismic sections from lines SE94-082 (A) and SE94-130 (B). Pattern occurs in northern part of study area in water depths generally > 20m and is interpreted as outcropping mud with sand lenses. Note more complex subbottom stratigraphy vs. prior figures due to channel fill deposits.

seafloor occurs suggests that this seafloor type is associated with sediments deposited within a large paleofluvial channel system known from previous surveys across this portion of the continental shelf (Riggs et al., 1992, 1995; Snyder, 1993) (Fig. 7) and appears to represent sediments which back-filled this channel.

Vibracores through “pock-marked” seafloor are dominantly mud with intercalated sand as laminae, lenses, and beds. This type of bedding suggests that they represent estuarine sediments which back-filled channels during episodes of sea-level rise. The “pock-marked” appearance of sonograms is interpreted to result from exposure of the intercalated sands among the dominantly muddy sediment on the seafloor.

Scarps

Hard-bottom may refer to any seafloor which is sufficiently indurated to stand out in relief against the surrounding seafloor. Riggs et al. (1996) provide a number of criteria for recognizing hard-bottoms from 3.5 kHz seismic profiles and side-scan sonograms. Unfortunately, several of these criteria (reflector attenuation, multiple amplification, fish signatures) are best expressed on 3.5 kHz seismic records, which were not obtained during the 1994 survey. Thus, recognition of hard-bottom sites within the northern Outer Banks sand resource area depends on the expression of surface relief producing scarps or sloped ramps which could be observed on both normal-incidence seismic and side-scan sonar profiles. Only a few vertical or near vertical features similar to hardbottom signatures reported from Onslow Bay (Riggs et al., 1998) were identified during this analysis (Fig. 8). The areal exposure of these hard-bottom sites is small; each of the observed hard-bottoms occupy <0.5 km^2. However, it is important to note that the data analyzed for this study are restricted to a 200 m swath on either side of survey tracklines with a 2-nautical mile spacing.

DISCUSSION and CONCLUSIONS

Correlation of seafloor types interpreted from side-scan sonar profiles with interpreted seismic data, vibracore data, and bathymetry, permits division of the study area into two general areas: 1) a southern area characterized by north-south oriented sand ridges with intervening troughs underlain by either medium to coarse sand with shell gravel or fine-grained (muddy) sediments veneered with coarse material and 2) a northern area with subdued bathymetry underlain by a dominantly mud facies with intercalated sand. The sand resource potential and distribution of environmentally sensitive hard-bottoms within each of these areas are discussed in detail below.

Southern Area

Examination of normal-incidence seismic profiles shows that strata in the shallow subbottom of the southern area dip gently to the east-southeast and are truncated on the west and north by the modern seafloor and by a large paleochannel crossing the inner shelf seaward of Kitty Hawk (Riggs et al., 1995; Fig. 7). The north-south oriented bathymetric highs are composed of a seismically transparent unit, suggesting that sediment composition through this unit is relatively uniform. Cores through this uppermost unit are dominantly fine sand, and side-scan sonograms over these bathymetric highs consistently display the uniform light gray acoustic signature. This unit is the most common sedimentary deposit across the southern portion of the study area. Observation of ripple marks on the sediment surface on some sonograms indicates that the surface of this unit is somewhat mobile. The broad areal

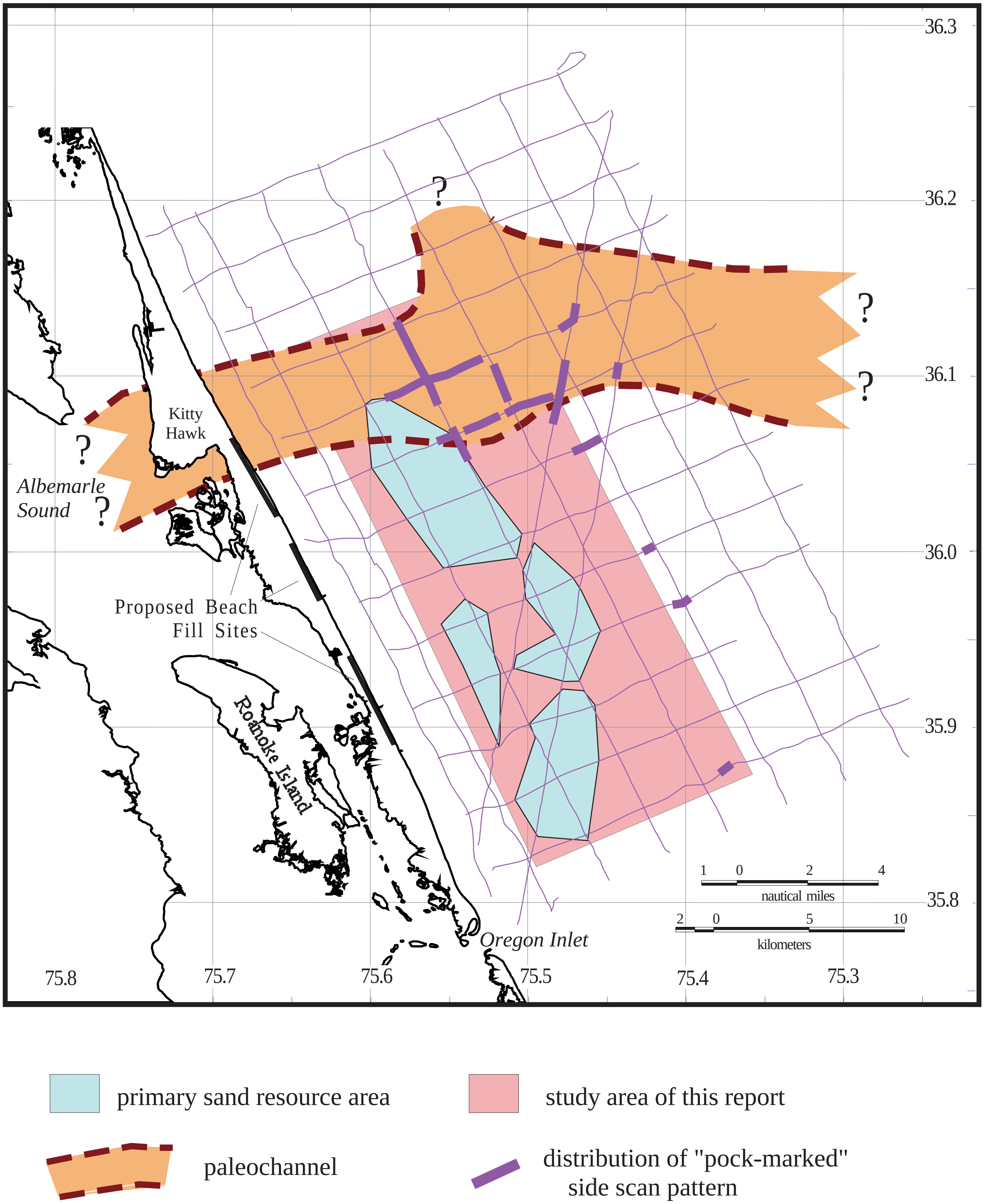
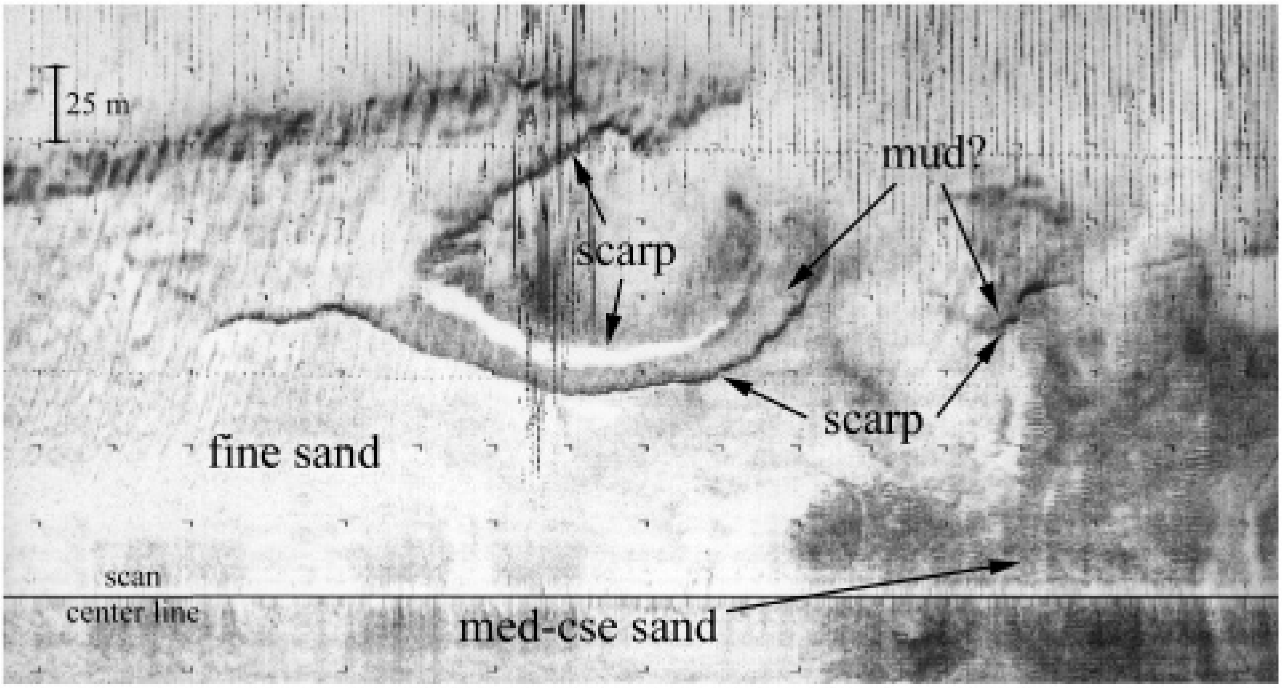


Figure 7. MMS Task Force area showing approximate location of large paleochannel that underlies the northern part of the study area of this report (channel location from S.W. Snyder, written communication, 1998). Note high coincidence of channel with distribution of "pock-marked" side-scan pattern.



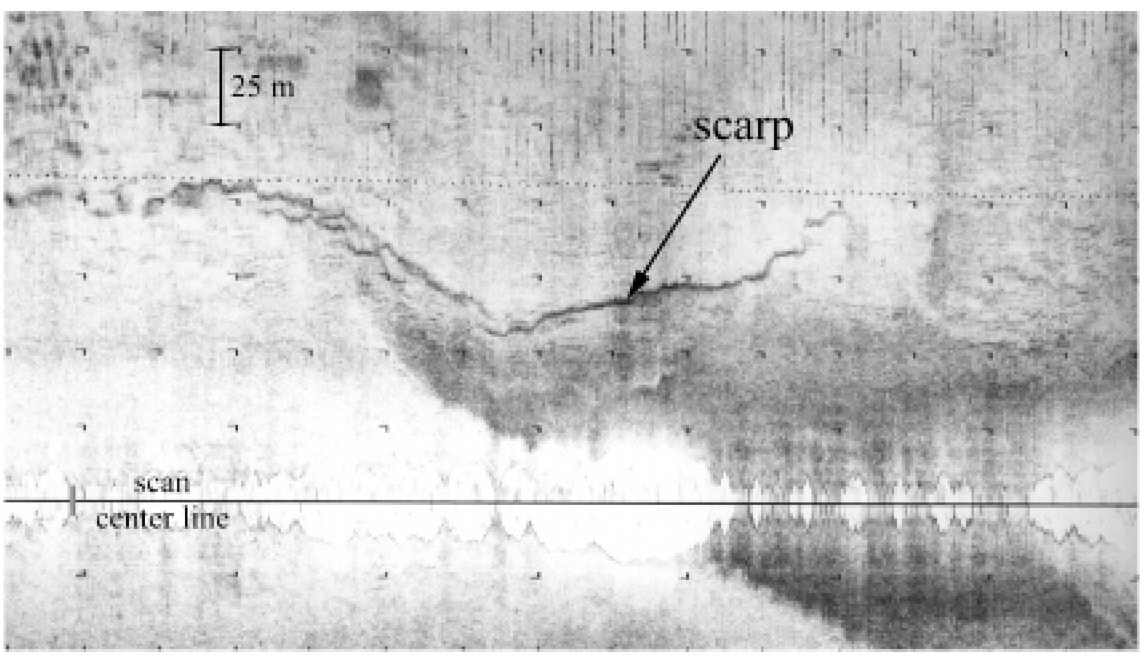


Figure 8. Sonograms showing small scarps that occur along lines SE94-080(A) and SE94-084 (B). These features are interpreted to be caused by more resistant material (probably cohesive mud) being exposed on slopes.

extent of this facies throughout the southern portion of the study area constitutes a significant potential sand resource (Boss and Hoffman,1997; Hoffman, 1998).

Medium to coarse sands with shell gravel are also found throughout the southern area, usually within the troughs separating the bathymetric highs. As previously mentioned, sonograms displaying uniform medium to dark gray acoustic signature are associated with the occurrence of this sediment on the floor of troughs. The sedimentologic/stratigraphic origin of these coarser sediments is not presently clear. Cores through the uppermost acoustically transparent facies often contain coarser sediment near their base which are believed to be similar to those sediments inferred to occur at the floor of troughs. Thus, this facies may represent an areally extensive, coarser-grained, basal deposit of the acoustically transparent facies or smaller, thin lenses of coarse sediment within the more uniform fine sand of the acoustically transparent facies.

Alternatively, these coarser sands may accumulate in troughs as winnowed lag deposits following major storms. This phenomenon has been observed in Onslow Bay (Riggs et al. 1998) where very coarse quartz sand and shell gravel accumulate in subtle depressions on the seafloor and are extensively reworked during major storms. Mobility of medium to coarse sand within the present study area is indicated by the presence of ripple marks across the sediment surface and it is conceivable that these deposits result from episodic reworking of the seafloor by storms. At present, the available data are insufficient to arrive at a definitive conclusion regarding the sedimentary origin or stratigraphic significance of this facies.

Within the southern portion of the study area, hardbottoms and potential hardbottoms were observed, but these are much less conspicuous and occupy smaller areas than the better-known hardbottoms observed in Onslow Bay (Riggs et al., 1996, 1998). Assuming that seafloor conditions along the available side-scan and seismic profiles are representative of conditions throughout the sand resource area proposed by Hoffman (1998), areal coverage by hardbottoms in the southern area is therefore relatively small. Several low relief scarps or gently sloping surfaces interpreted as possible hardbottoms occur adjacent to the flanks of the northern extensions of the (sandy) bathymetric highs. These ramps are apparently formed by the outcrop of more cohesive (muddy) sediment at the “toe” of the bathymetric highs (Fig. 9) and may support burrowing and boring organisms similar to those known from Onslow Bay (Riggs et al. 1998).

Northern Area

The northern portion of the study area is characterized by subdued bathymetric relief over much of the region. This subdued relief results in part from the fact that a large fluvial channel caused extensive erosion across this portion of the continental shelf during the Quaternary (Riggs et al. 1995). Vibracores through this channel are dominantly muddy, with intercalated silt and very fine sand in discontinuous lenses interpreted to be of estuarine origin. Thus, this large paleofluvial channel was back-filled with estuarine deposits during sea-level rise events.

The predominance of muddy sediment filling the channeled northern portion of the study area presents a relatively poor potential sand resource. Over much of the northern portion of the study area, side-scan sonograms display the distinctive “pock-marked” signature associated with the mixed sandy mud of the channel-fill facies. These cohesive muddy deposits may represent hardbottoms despite the absence of relief because there is little other sediment to bury or mask these cohesive surfaces. As such, this low-relief seafloor may also support a rich and diverse population of infauna similar to those

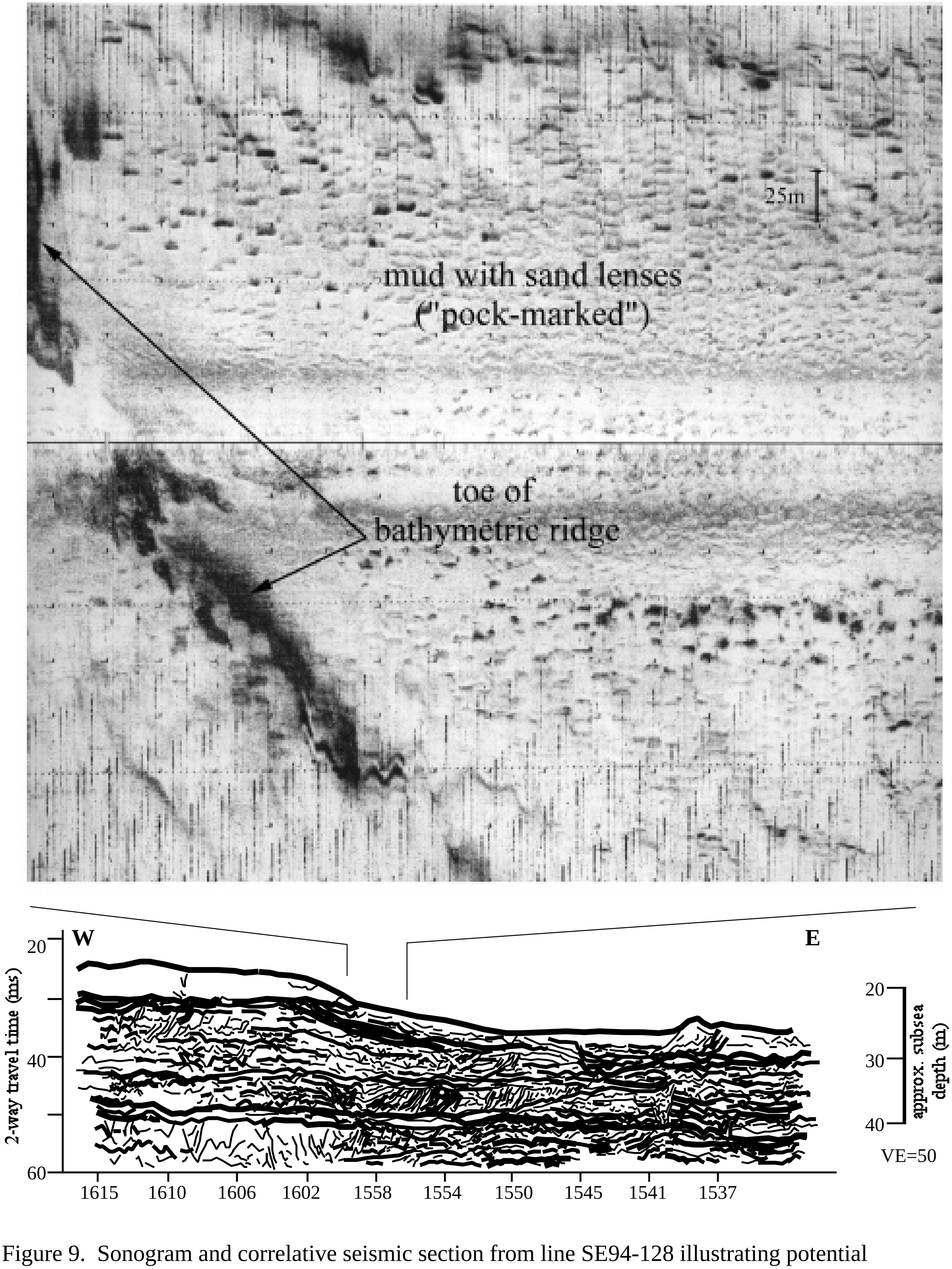


Figure 9. Sonogram and correlative seismic section from line SE94-128 illustrating potential hardbottom along sloped surface east of a bathymetric high. The side-scan signature indicates the ramped surface is underlain by dominately muddy sediment ("pock-marked") sonogram pattern.

found on “high-relief” hardbottoms of Onslow Bay (Riggs et al., 1998). However, due to the low-relief and the high-energy dynamics of this shelf environment, it is probable that these hardbottoms are transient features of the seafloor; major storms may redistribute sediment on the shelf such that some hardbottom areas will become covered whereas new hardbottom areas will be exhumed.

When exposed, these new hardbottom sites can be important benthic habitats because they present new space on which benthos may become established; when covered with a even a thin layer (i.e. few cm) of loose sediment, however, they become non-productive (Renaud et al., 1996a; 1996b). Thus it is important to understand the seasonal, annual, and longer term dynamics of sediment movement on the shelf and its impact on hardbottom evolution, particularly as this may relate to sediment resuspended by future sand dredging operations.

Presently, the ecological dynamics of these seafloor hardbottom communities and their contribution to biological productivity offshore the northern Outer Banks are poorly understood. Future surveys in this area could focus on identifying these habitats and mapping their areal and temporal extent using towed video or ROV traverses.

The analyses presented herein demonstrate the utility of integrated geophysical, sedimentological, and stratigraphic methods in the study of shallow continental shelf environments. The seismic reflection profiles provide a means for constructing a stratigraphic framework for the study area, whereas the side-scan sonar records permit characterization and interpretation of seafloor types. Cores through representative seafloor types are critical to these analyses as they provide “ground truth” for geophysical interpretations. Together, these data sets provide for development of a coherent stratigraphic model and assist greatly in predicting the location and areal distribution of sand resources as well as potential environmentally sensitive areas on the continental shelf.

Prior to initiation of large-scale sand-dredging operations, additional integrated surveys with more closely-spaced gridlines can assist in refining boundaries of actual sand resources, provide more detailed volume estimates of the sand resource, and identify with greater resolution sites such as livebottoms which might be adversely affected by dredging operations.

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Preliminary Map of Seafloor Types from Side Scan Sonar Sonograms -
Inner Shelf offshore of Northern North Carolina Outer Banks

Plate 1
Boss, Hoffman, and Riggs
MMS Contract Report